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THE HALL EFFECT ANNUAL REPORT

During the year the Hall effect research program moved through several milestones. The equipment was acquired which will allow conventional Hall effect measurement to be made at Virginia State University. The program involved two undergraduates and one graduate students in the system development. A working relationship was developed with the Naval Research Laboratory was also commenced. This contact will allow the performance of Quantum Hall effect.

We also consulted Dr. Robert Coleman at the University of Virginia. He is during Hall Effect experiments. The principal investigator also attended a short course in Radiation Damage through the auspices of the IEEE a Monterey, California.

The measurement system at Virginia State University consists of a Walker Scientific Power supply (from 0 to 50 amp), an alpha Magnet, a digital Gaussmeter, a HP 9816 computer with peripherals, a 3497A data acquisition will be used to acquire and analyze the data. A cryostat has also been acquired.

Roscoe Ledbetter, an undergraduate student has developed a computer program for data acquisition. A program to process and analyze the data is nearing completion. The decision has been made to operate two systems of sample geometries. One employs the standard Hall sample configuration. The other will utilize the Van der Pauw technique.

The experimental procedure as we have perceived it consists of the measurement of the Hall coefficient, resistivity, and Hall mobility as a function of temperature of a sample of Gallium Arsenide before and after irradiation with low and high energy protons. In order to compare the results with the known damages that are produced by proto irradiation , one need to know the relationship among the quantities that radiation damage and the Hall effect measurements have in common.

It is known that the effect of radiation damage is associated with the carrier concentration and the Hall mobilities . The manifestation of the radiation defects are "intrinsic defects". In order to establish and test the theory , a theoretical model is being developed using Lindhard's theory of atomic collisions.

The second most important step is to link the quantum Hall effect and the changes produced by proton collisions. Work has begun on the the development of a theory and subsequently experiments will be designed and performed.

APPENDIX I

RESISTIVITY AND HALL COEFFICENT MEASUREMENTS

VAN DER PAUW METHOD

The measurement theory developed by Van der Pauw involves the use of arbitrary geometric configurations . Incumbent adjustments are made for the chosen geometry. For our system consider a lamella

In order to make resistivity measurements a current I is passed through two adjacent contacts e.g. (2 and 3), the voltage V is then measured across the other contacts. The equation R = V/I is used. Next a curremt I' is passed through the next pair of contacts (3,4) and the voltage V' is measured across the other contacts. The equation R' = V'/I' is used. The resistivity ' ' of sample of thickness 't' is related to R and R' through the relation Exp(- tR/) + Exp(- tR'/) = 1. The resistivity can thus be obtained.

In order to determine the value of the Hall coefficient, a current I is passed through two non adjacent contacts and the voltage V is measured across the other two. The relation R = R/I is used. The magnetic field is now energized and the measurements of V' and I' are then made on the same contacts. The Hall coefficient R_H can now be determined from u = R_H/ .

The measurement process consists passing a current through both directions and averaging the results. The magnetic field is reversed and measurements taking in both direction and averaged.

The following relations are typical for the experimental determination of the resistivity and Hall mobility. All measurement are made as a function of temperature.

$$= t/\ln 2(V_{23}/2I_{14} + V_{24}/2I_{31})\ f$$

$$u_H = (V^{H}_{32}\ )2\ln 2/\ B(V_{21}/I_{34} + V_{13}/I_{42})f$$

```
10     ! CURVE FITTING PROGRAM FOR HALL EFFECT DATA HENDERSON JORDAN FEB 7,1986
11     ! IDENTIFIERS
13     !      C1      COEF            SOLUTION VECTOR
14     !      C3      CORREL          CORRELATION COEFFICIENTS
15     !      E2      SIGMA           VECTOR OF ERRORS
16     !      E5      SEE             STD ERROR OF ESTIMATE
17     !      L3      NLIN            NUMBER OF PLOT LINES
18     !      M1      MAX             MAXIMUM LENGTH
19     !      N1      NROW            NUMBER OF ROWS
20     !      N2      NCOL            NUMBER OF COLUMNS
21     !      R3      RESID           VECTOR OF RESIDUALS
22     !      S7      SUMY            SUM OF Y
23     !      S8      SUMY2           SUM OF Y SQUARED
24     !      T6      SRS             SUM OF RESIDUALS SQUARED
25     !      Y3      YCAL            CALCULATED Y
26     ! END OF IDENTIFIERS
40     A$="DDD  DD.D  "
50     C$="DDD   DD.d"
60     M1=35
70     DIM Z(4),A(4,4),C1(14),Y(35),U(35,4)
80     DIM W(4,1),B(4,4),I2(24,23),X(35),Y1(35)
90     DIM Y2(35),R3(35),E2(4)
100    GRAPHICS OFF
110    PRINT
120    PRINT " UP TO THIRD DEGREE POLYNOMIAL  LEAST SQUARES FIT BY GAUSS JORDAN E
LIMINATION"
130    PRINT
140    GOSUB 500       ! GET THE DATA
150    ! SORT THE DATA
160    GOSUB 800        !  SQUARE UP THE MATRIX
170    GOSUB 4000       !  SET UP THE MATRIX
180    GOSUB 5000       !  GAUSS-JORDAN SOLUTION
190    GOSUB 1000       !  PRINT THE RESULTS
200    GOSUB 7000       !  PLOT DATA
210    GOTO 100
500    !  GET THE DATA
510    INPUT "NUMBER OF DATA POINTS",N1
520    INPUT "POLYNOMIAL ORDER",N2
530    IF N2>3 THEN 520
540    IF N2<1 THEN 9999
550    N2=N2+1
560 L3=(N1-1)*2+1
570    IF N4=1 THEN 620
580    FOR I=1 TO N1
600    READ X(I),Y1(I)
610    NEXT I
620    RETURN
630    ! Y DATA
640    DATA 1,2.07,2,8.6,3,14.42,4,15.8,5,18.92,6,17.96
650    DATA 7,12.98,8,6.45,9,.27
660    RETURN   ! FROM INPUT ROUTINE
800    ! SET UP THE MATRIX DATA
810    FOR I=1 TO N1
820    U(I,1)=1
830    FOR J=2 TO N2
840    U(I,J)=U(I,J-1)*X(I)
850    NEXT J
860    Y(I)=Y1(I)
870    NEXT I
```

```
800 RETURN   ! FROM SETTING UP DATA MATRIX
1000! CALCULATE RESIDUALS AND PRINT RESULTS
1001 PRINTER IS 701
1010  S7=0
1020  S8=0
1030  T6=0
1040  FOR I=1 TO N1
1050  Y3=0
1060  FOR J=1 TO N2
1070  Y3=Y3+C1(J)*U(I,J)
1080  NEXT J
1090  R3(I)=Y3-Y(I)
1100  Y2(I)=Y3
1110  T6=T6+R3(I)^2
1120  S7=S7+Y(I)
1130  S8=S8+Y(I)^2
1140  NEXT I
1150  C3=SQR(1-T6/(S8-S7^2/N1))
1160  IF N1=Ns THEN E5=SQR(T6)
1170  IF N1<>N2 THEN E5=SQR(T6/(N1-N2))
1180  FOR J=1 TO N2
1190  E2(J)=E5*SQR(ABS(B(J,J)))
1200  NEXT J
1210  PRINT "          X          Y          YCAL          RESID"
1220  FOR I=1 TO N1
1230  PRINT USING "5X,DD,6X, DDD.DD,6X,DDD.DD,6X,DDD.DD,6X,DDD.DD";I,X(I),Y(I),Y
2(I),R3(I)
1240  NEXT I
1250  PRINT
1260  PRINT "COEFFICIENT      ERRORS"
1270  PRINT USING "5X,DDD.DD,3X,DDD.DD";C1(1),E2(1)
1290  FOR I=2 TO N2
1300  PRINT USING "5X,DDD.DD,3X,DDD.DD";C1(I),E2(I)
1310  NEXT I
1320  PRINT
1330  PRINT USING "10X,27A,1X,DDD.DD";"CORRELATION COEFFICIENT IS",C3
1331  PRINT
1332  PRINT
1333  PRINT "EQUATION  OF CURVE"
1334  PRINT USING "10X,DDD.DD,1X,1A,1X,DDD.DD,1A,1X,1A,1X,DDD.DD,3A,1X,1A,DDD.DD
,5A";C1(1),"+",C1(2),"X","+",C1(3),"X*X","+",C1(4),"X*X*X"
1336  WAIT 10
1337  PRINTER IS 1
1340  RETURN ! FROM PRINTOUT
4000  ! U AND Y CONVERTED TO A AND Z
4011  ! IDENTIFIERS
4013  !     N1     NROW      NUMBER OF ROWS
4014  !     N2     NCOL      NUMBER OF COLUMNS
4015  !     END OF IDENTIFIERS
4020        FOR K=1 TO N2
4030        FOR L=1 TO K
4040        A(K,L)=0
4050        FOR I=1 TO N1
4060        A(K,L)=A(K,L)+U(I,L)*U(I,K)
4070        IF K<>L THEN A(L,K)=A(K,L)
4080        NEXT I
4090        NEXT L
4100        Z(K)=0
4110        FOR I=1 TO N1
4120        Z(K)=Z(K)+Y(I)*U(I,K)
4130        NEXT I
4140        NEXT K
5000        ! JORDAN MATRIX INVERSION AND SOLUTION
5010        ! FEB 7, 1986
5011        !   IDENTIFIERS
5012        !   A      A       COEFFICIENT MATRIX
```

```
5014     !    B1      BIG     BIGGEST VALUE
5015     !    C1      COEF    SOLUTION VECTOR
5016     !    D3      DETERM  DETERMINANT
5017     !    E1      ERMES   ERROR FLAG
5018     !    H1      HOLD    WORK VARIABLE
5019     !    I2      INDEX   WORK MATRIX
5020     !    I3      IROW    ROW  INDEX
5021     !    I4      ICOL    COLUMN INDEX
5022     !    I5      INVRS   PRINT- INVERSE FLAG
5023     !    N2      NCOL    NUMBER OF COLUMNS
5024     !    N3      NVEC    NUMBER OF CONSTANT VECTORS
5025     !    P1      PIVOT   PIVOT INDEX
5026     !    W       W       SOLUTION MATRIX
5027     !    Z       Z       CONSTANT VECTOR
5029     !    END OF IDENTIFIERS
5080     !
5090     E1=0 ! BECOMES 1 FOR SINGULAR MATRIX
5100     I5=1 ! PRINT INVERSE MATRIX IF ZERO
5110     N3=1 ! NUJMBER OF CONSTANT VECTORS
5120     FOR I=1 TO N2
5130     FOR J=1 TO N2
5140     B(I,J)=A(I,J)
5150     NEXT J
5160     W(I,1)=Z(I)
5170     I2(I,3)=0
5180     NEXT I
5190     D3=1
5200     FOR I=1 TO N2
5210     !
5220     !  SEARCH FOR LARGEST (PIVOT) ELEMENT
5230     !
5240     B1=0
5250     FOR J=1 TO N2
5260     IF I2(J,3)=1 THEN 5350
5270     FOR K=1 TO N2
5280     IF I2(K,3)>1 THEN 6120
5290     IF I2(K,3)=1 THEN 5340
5300     IF B1>=ABS(B(J,K)) THEN 5340
5310     I3=J
5320     I4=K
5330     B1=ABS(B(J,K))
5340     NEXT K
5350     NEXT J
5360     I2(I4,3)=I2(I4,3)+1
5370     I2(I,1)=I3
5380     I2(I,2)=I4
5390     !  INTERCHANGE ROWS TO PUT PIVOT ON DIAGONAL
5400     IF I3=I4 THEN 5540
5410     D3=-D3
5420     FOR L=1 TO N2
5430     H1=B(I3,L)
5440     B(I3,L)=B(I4,L)
5450     B(I4,L)=H1
5460     NEXT L
5470     IF N3<1 THEN 5540
5480     FOR L=1 TO N3
5490     H1=W(I3,L)
5500     W(I3,L)=W(I4,L)
5510     W(I4,L)=H1
5520     NEXT L
5530     ! DIVIDE PIVOT ROW BY ELEMENT
5540     P1=B(I4,I4)
5550     D3=D3*P1
5560     B(I4,I4)=1
5570     FOR L=1 TO N2
```

```
5590       NEXT L
5600       IF N3<1 THEN 5660
5610       FOR L=1 TO N3
5620       W(I4,L)=W(I4,L)/P1
5630       NEXT L
5640       !
5650       ! REDUCE NONPIVOT ROWS
5660       FOR L1=1 TO N2
5670       IF L1=I4 THEN 5770
5680       T=B(L1,I4)
5690       B(L1,I4)=0
5700       FOR L=1 TO N2
5710       B(L1,L)=B(L1,L)-B(I4,L)*T
5720       NEXT L
5730       IF N3<1 THEN 5770
5740       FOR L=1 TO N3
5750       W(L1,L)=W(L1,L)-W(I4,L)*T
5760       NEXT L
5770       NEXT L1
5780       NEXT I
5790       !
5800       !  INTERCHANGE COLUMNS
5810       !
5820       FOR I=1 TO N2
5830       L=N2-I+1
5840       IF I2(L,1)=I2(L,2) THEN 5920
5850       I3=I2(L,1)
5860       I4=I2(L,2)
5870       FOR K=1 TO N2
5880       H1=B(K,I3)
5890       B(K,I3)=B(K,I4)
5900       B(K,I4)=H1
5910       NEXT K
5920       NEXT I
5930       FOR K=1 TO N2
5940       IF I2(K,3)<>1 THEN 6120
5950       NEXT K
5960       E1=0
5970       FOR I=1 TO N2
5980       C1(I)=W(I,1)
5990       NEXT I
6000       IF I5=1 THEN 6140
6010       PRINT
6020       PRINT "  MATRIX INVERSE"
6030       FOR I=1 TO N2
6040       FOR J=1 TO N2
6050       PRINT USING "10X,DDD.D";B(I,J)
6060       NEXT J
6070       PRINT
6080       NEXT I
6090       PRINT
6100       PRINT "DETERMINANT =",D3
6110       RETURN  ! IF INVERSE IS PRINTED
6120       E1=1
6130       PRINT "ERROR-MATRIX SINGULAR"
6140       RETURN ! FROM GAUSS-JORDAN SUBROUTINE
7000  PRINT "DO YOU WANT A GRAPH OF THE FUNCTION  (Y/N)"
7001  INPUT K$
7002  IF K$="Y" THEN 7009
7003  IF K$="N" THEN 9999
7009  ! PLOT OF Y AND Y2 AS A FUNCTION OF X, FEB. 5,1985
7010  C$=CHR$(255)&"K"
7020  DUMP DEVICE IS 701,EXPANDED
7030  OUTPUT 2 USING "#,K";C$        ! Clear leftover display
7040  PRINT
```

```
7060  OUTPUT 2 USING "#,K";C$          ! Clear screen for graph
7070  PRINT "WHAT X AND Y LABELS DO YOU WANT ON GRAPH"
7080  INPUT T1$,T$
7081  INPUT "MAXIMUM X,Y",N4,N5
7090  GINIT                            ! Initialize various graphics parametersGRAP
7100  PLOTTER IS CRT,"INTERNAL"        ! Use the internal screenGRAPHICS OFF
7110  GRAPHICS ON                      ! Turn on the graphics screenGRAPHICS OFF
7120  X_gdu_max=100*MAX(1,RATIO)       ! Determine how many GDUs wide the screen is
7130  Y_gdu_max=100*MAX(1,1/RATIO)     ! Determine how many GDUs high the screen is
7140  LORG 6                           ! Reference point: center of top of label
7150  DEG                              ! Angular mode is degrees (used in LDIR)
7160  LDIR 90                          ! Specify vertical labels
7170  CSIZE 4.5                        ! Specify smaller characters
7180  MOVE 0,Y_gdu_max/2               ! Move to center of left edge of screen
7190  LABEL T$         ! Write Y-axis label
7200  LORG 4                           ! Reference point: center of bottom of label
7210  LDIR 0                           ! Horizontal labels again
7220  MOVE X_gdu_max/2,.07*Y_gdu_max! X: center of screen; Y: above key labels
7230  LABEL T1$          ! Write X-axis labelGRAPHICS OFF
7240  VIEWPORT .1*X_gdu_max,.98*X_gdu_max,.15*Y_gdu_max,.9*Y_gdu_max
                                       ! Define subset of screen area
7250  FRAME                            ! Draw a box around defined subset
7260  WINDOW 0,N4,0,N5
7270  AXES 1,1,0,0,10,10,5    ! Draw axes with appropriate ticks
7280  CLIP OFF                         ! So labels can be outside VIEWPORT limits'
7290  CSIZE 1.6,1.6                    ! Smaller chars for axis labelling
7300  LORG 6                           ! Ref. pt: Top center      |\
7310  FOR I=0 TO N4 STEP N4/10         ! Every 10 units           | \
7320    MOVE I,-.1                     ! A smidgeon below X-axis |  >  Label X-axis
7330    LABEL USING "#,DD.D";I         ! Compact; no CR/LF        | /
7340  NEXT I                           ! et sequens               |/
7350  LORG 8                           ! Ref. pt: Right center     |\
7360  FOR I=0 TO N5 STEP N5/10         ! Every quarter             | \
7370    MOVE -.05,I                     ! Smidgeon left of Y-axis  |  > Label Y-axi
s
7380    LABEL USING "#,DD.D";I   ! DD.D; no CR/LF              | /
7390  NEXT I                           ! et sequens                |/
7400  PENUP
7410  I=0
7420  FOR I=1 TO N1
7430     PLOT X(I),Y(I)
7440  NEXT I
7450  MOVE 0,0
7460  FOR K=1 TO N1
7470  PLOT X(K),Y2(K)
7480       NEXT K
7490  PRINT "IF YOU WANT A HARD COPY OF GRAPH PRESS DUMP GRAPHICS"
7491  PRINT "IF NOT PRESS CONTINUE"
7492  PAUSE
7493  GRAPHICS OFF
7500  PRINT "DO YOU WANT TO PLOT ANOTHER SET OF DATA Y/N"
7510  INPUT Z$
7520  LABEL TIME$(TIMEDATE),DATE$(TIMEDATE)
7530  IF Z$="Y" THEN 100
7540  IF Z$="N" THEN 9999
7550  RETURN
7560  GRAPHICS OFF
7570   OUTPUT 2 USING "#,K";C$
9999  END
```

REFERENCE

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Changes in the Electrophysical characteristics of n-type Silicon as a Result of Irradiation with 6.3 Mev Protons
Sov. Phys. Semicond. 18(2) February 1984

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Positions of Acceptor levels of Divacancy in the band gap of n-type Silicon irradiated with 6.3 Mev Protons
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Mat. Fys. Medd. Dan. Vid. Selsk. 33 no. 14 (1963)

Student Participation

During the Spring 1985 semester six graduate students were participating in the program, Lucian R. Goode, Jr., Akpan E. Akpan, Nana Adu, William Bolden, Larry Brown and Karamali Shojaei. Goode, Adu and Shojaei are working on MuSR projects; Akpan, Bolden and Brown are working on computer modeling of radiation damage in solids. In September 1985 another graduate student, Li-Tai Song, joined the institute and is working on Hall effect studies.

During the Spring 1985 semester four undergraduate students participated, Michael Davis, Roscoe Ledbetter, Cornelia Belsches and Raymond Noel. Fall 1985 undergraduates were Davis, Ledbetter, Belsches and Tony Barnes.

Other Activities

The director of the institute participated in an experiment on inelastic scattering of polarized protons from ^{12}C at the Los Alamos Meson Physics Facility in New Mexico during July/August and November/December 1985. Karamali Shojaei, a VSU graduate student, participated in the July/August run. Other collaborators included Bernard J. Lieb of George Mason University, Herbert O. Funsten, Charles F. Perdrisat and J. Michael Finn of the College of William and Mary, Hans S. Plendl of Florida State University, Joseph Comfort of Arizona State University, and one graduate student each from William and Mary, Florida State and Arizona State.

An abstract of a paper to be presented at the April 1986 APS meeting is included as Appendix 6. We are seeking other sources of funding for our participation in these experiments and hope for success in the near future.

Two papers based on work done at the Tri-University Meson Facility (Vancouver, BC) in 1979-80 and supported in part by NASA grant NSG 1646 were completed in

1985 with extremely minor support from NAG-1-416. Both were accepted for publication by Physical Review C. "Energy dependence of the $^7Li(p,d)^6Li$ reaction" appeared in the September 1985 issue and a reprint is included here as Appendix 7. "$^4He(\vec{p},d)^3He$ reaction at 200 and 400 MeV" is scheduled to appear in the February 1986 issue and a preprint is included here as Appendix 8.

The director participated in the revision of a paper based on pion-nucleus reaction experiments conducted at LAMPF in 1980 and supported in part by NASA grant NSG-1646. This revised version has been submitted to Physical Review C and a preprint is included here as Appendix 9.

The director of the institute has served as the Virginia State University representative on the board of trustees of the Southeastern Universities Research Association since October 1983. During 1985 he served on the SURA industrial affiliates committee and in early January 1986 was appointed to the science and technology committee of SURA. This committee will provide SURA oversight for the Continuous Electron Beam Accelerator Facility, which is a 4-GeV continuous wave electron accelerator to be constructed in Newport News, Virginia.

In May 1985 the director completed a one-year term as chairman of the astronomy, mathematics and physics section of the Virginia Academy of Science. He was also appointed to the local organizing committee for the International Symposium on the Physics and Chemistry of Small Clusters, which will take place in October 1986 in Richmond, Virginia.

James C. Davenport served as director of the summer student program at Fermilab (Batavia, Illinois) during the summer of 1985. He also served on the Committee on Minorities in Physics of the American Physical Society this past year.

George W. Henderson, John J. Stith and Larry D. Brown (graduate student) received course credit in the summer of 1985 for an IEEE-NSRE tutorial short course on radiation effects through the New Jersey Institute of Technology.

Equipment and Supplies

The following items were purchased during the reporting period:

1 Janis supertran helium transfer tube
4 EMI 9907B photomultiplier tubes
3 Ortec 265 tube bases
3 Ortec 218 phototube shields
1 EG&G/Ortec 567 Time-to-amplitude converter
1 PDP 11/73 computer (1-megabyte memory, 31-megabyte hard disk drive, dual floppy disk drives, terminal and printer
1 Interface Standards IS-11/CC CAMAC crate controller
2 Keithley 175 multimeters
1 Keithley 197 multimeter
3 Hewlett-Packard HP-15C calculators
100 reprints of our paper on MuSR in strained single crystals of iron
1 1-megabyte memory board for HP 9816S computer
1 Hewlett-Packard terminal emulator
1 Hewlett-Packard 9816S computer with accessories
1 Hewlett-Packard HP 3497A data acquisition control unit
1 MICRO/RSX operating system for PDP-11/73 computer
3 PVC inserts and magnetic shields for phototubes

In addition, the internal account at Brookhaven National Laboratory was continued in force. This enables the institute to purchase equipment, supplies and materials from BNL directly while experiments are in progress.

Three peripherals for the PDP 11/73 computer were ordered (plotter, modem, line filter) and received in early 1986. Several others (IEEE bus, QNIVERTER, and Advanced Programmers Kit) are still on order. A quadruple constant fraction discriminator and a scientific word processing program are also on order.

Summary

The second year of support from NASA for the Solid State Physics Research Institute was a year of growth and consolidation. The MuSR program saw a major publication, substantial progress on several other projects and near completion of the new data acquisition and analysis system (which should be complete in time for experiments in the spring of 1986. The radiation damage studies have gone into production mode, and the Hall effect apparatus is essentially complete. The number of student participants increased substantially over the 1984 level.

The higher level of student interest has enabled the principal investigators to set higher standards for student eligibility for research stipends, and the quality of student involvement showed marked improvement as we began the spring 1986 semester.

We look forward to another active and successful year in 1986, and we appreciate the support from NASA which makes these activities possible.

Respectfully submitted,

Carey E. Stronach

Carey E. Stronach
Director
February 14, 1986